Economic evaluation of efficiency of investments into energy-saving controlled electric drives of conveyers of mining and processing works

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Abstract
On the base of researches of statistical characteristics of in-pit cargo flow at mining and processing works it is based the application of energy-saving controlled electric drive of conveyor units, used for transport of ore on the objects of surface complex. Economic evaluation of efficiency of investments is fulfilled, basic technology factors, which affect making of investment decisions, are determined.
Key words: CONVEYOR UNITS, CONTROLLED ELECTRIC DRIVE, ENERGY SAVING, CAPITAL INVESTMENT PROJECT, ECONOMIC EFFICIENCY

Powerful conveyor units, used for ore and hard rock transportation from open-pits to the objects of surface complex have become a frequent practice at mining and processing works of Kryvyi Rih iron-ore basin [1]. Installed capacity of electric drive motors of the most energy-intensive achieves 3-4 MW per conveyer, herein ore transportation from open-pit at the surface is fulfilled under 2-3 stage scheme considering mining and geological conditions of the pit.

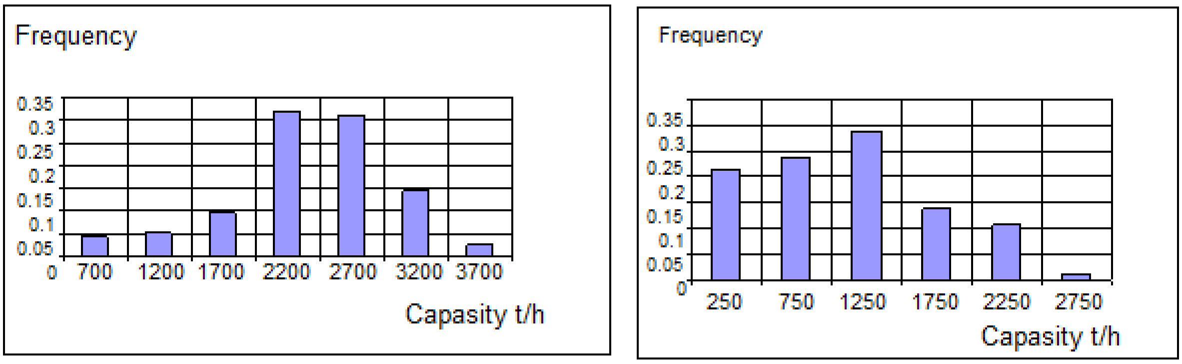
The main reserve for increase of effectiveness of conveyer units of mining and processing works is conditioned by application of noncontrolled in speed systems of electrical drive systems, design decisions of which were taken without considering the tasks of energy saving.

Project of the last years started to provide for possible regulation of speed of powerful conveyers, however the range of operational factors prevents hte large-scale implementation of regimes of energy-saving rate control.

Working rhythm of conveyer units to a large extent is determined by the character of in-pit flow of cargo, formed in conditions of existing technology of open-pit mining and central continuous flow process technology of delivery. The experience of Kryvyi Rih iron-ore basin exploitation speaks for the presence of wide fluctuations of working capacity of cargo flow, which arrives at the conveyer units of central continuous flow process technology of delivery. Nonuniformity of ore input to the conveyers determines in many ways the varying duty of conveyer, which in conditions of nonregulated speed is characterized by nonuniformity of conveyer belt loading, real values of which, as a rule, are significantly lower than nominal (design) value. Conveyer light load leads to that significant piece of energy, spent for conveyor drive, is loosely used.

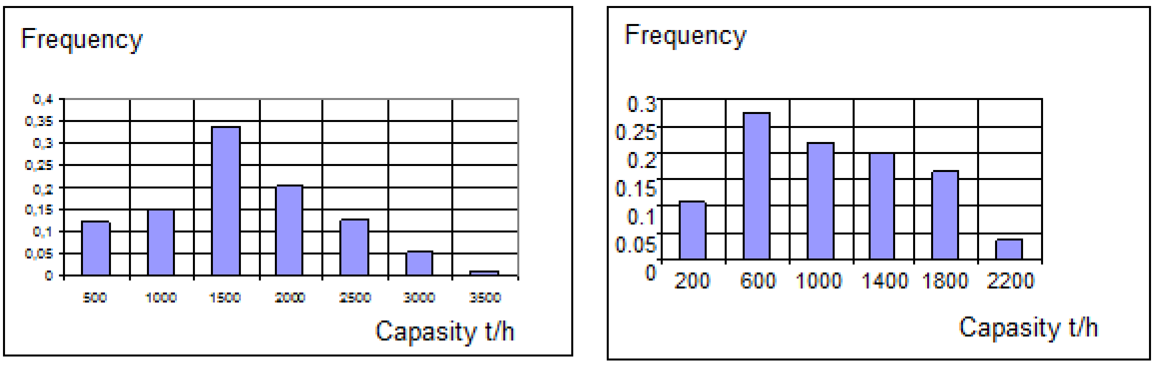
A significant number of publications concerning the necessity and efficiency of various ways of control of the velocity of conveyer units are known. These questions were considered in works [2-5] in a detailed way. The main directions of researches are devoted to the questions concerning grounding of electrical drive systems, securing of required conveyer starting conditions, choice of conversion transducer for conveyer rate control, evaluation of the influence of the rate for wear of conveyer belt etc. However, considering that for the most operating conveyer units securing of velocity mode control is connected with the necessity of investment outlay, the questions about grounding of the efficiency of investments into regulation of conveyer speed are insufficiently investigated.

Statistical characteristics of nonuniform input of cargo on the conveyer units are determined with the help of investigations fulfilled in conditions of Annovskiy and Pervomayskiy open-pits of PJSC “SevGOK”. Distribution histograms of actual loads in the ore and hard rock (one-hour efficiency) under the conditions of analysis of representative samples are shown in the figure 1-2.



a) b)

Figure 1. Distribution histogram of capacity of Pervomayskiy open-pit
a) in ore; б) in hard rock



a) b)

Figure 2. Distribution histogram of capacity of Annovskiy open-pit
а) in ore; б) in hard rock

Presented data speaks for rather wide range of change of conveyer unit loads that predetermine the necessity of research of economically sufficient depth of conveyer rate control.

Wound-rotor induction motor is often used as drive motor for heavy conveyers. This variant is the most acceptable both from the point of view of technological and performance parameters (reliability, overload capability, starting characteristics) and according to economic considerations. 2 and 3 motor schemes are used for drivegear of powerful conveyers. Rate control of such driving motor is provided by wound-rotor slip recovery system with energy output of motor slip during rate control into electric network.

Let us estimate cost and revenue sides of the project regulated in conveyer speed for nominal parameters of electrodrive (3x1000kW) in conditions of central continuous flow process technology of Pervomayskiy open-pit of PJSC “SevGOK”.

Capital costs we will define as the sum of constant component (not depending on the depth of rate control) A and cost variable component, which is proportional to the required depth of rate control with coefficient of proportionality B:

$$K=A+B\cdot\left(\frac{v_n - v_{\min}}{v_n}\right) = A+B\cdot(1- v_{min}*),$$

where v_n – nominal conveyer rate; v_{min} – minimal under the condition of required depth of conveyer; v_{min}*– minimal velocity in relative units.

Constant component of capital costs A corresponds to the acquisition cost, assembling and debugging of control system (programmable controller, extra-fixed detectors, etc), cost of which does not depend on the equipment capacity.

Let us take control system cost A= 40 000 €, which corresponds to the price and cost of installation and checkout works for controllers of «Schneider Electric». The cost of 3 equipment sets (3 -motor drive) in the rotary motor circuit, according to maximum depth of rate control is (taking into account installation and checkout work) B = 450 000 €.

Profit element of the project – is the economy of payment for electricity of regime with regulated velocity in relation to the regime without control. Within the range of rates from nominal (v_n) to the chosen minimal (v_{min}) rate, linear load of 1m of conveyer belt by means of regulation of velocity is constant, i.e. in this range the capacity of conveyer Q is proportional to conveyer velocity v, and in relative units $Q^*=v^*$. For minimal velocity of control range $Q_0^*=v^*_{min.}$. At the performance values of incoming flow of cargo less than Q_0 conveyer rate is not controlled and equals v_{min}.

Using real statistics of incoming flow of cargo, one may determine the averaged value of required power of conveyer drive within certain long period of time under the following formula:

$$N_{av.} = \int_0^{Q_0} N_1(Q)\,p(Q)\,dQ + \int_{Q_0}^{Q_н} N_2(Q)\,p(Q)\,dQ$$

where $N_1(Q)$, $N_2(Q)$ – are the dependences required power on the capacity at noncontrolled conveyer speed (index 1) and regulated speed (index 2) respectively; $p(Q)$ – probability density of conveyer load distribution (function, which is represented as approximated productivity histogram).

Let us calculate conveyer input power in relative units. As the base let us take capacity consumed in nominal regime of conveyer work at nominal capacity Q_n and nominal velocity v_n: ($N^*_{av.}= N_{av.} / N_n$). Considering that $Q_0^*=v^*_{min}$ и $v^*_n= Q^*_n =1$, we will have:

$N^*_{av}\cdot(v^*_{min})=$

$$\int_0^{v^*_{\min}} N^*_1(Q^*)\,p(Q^*)\,dQ^* + \int_{v^*_{\min}}^{1} N^*_2(Q^*)\,p(Q^*)\,dQ^*$$

And annual saving of costs for energy consumption will be as follows:

$E(v^*_{min})= \tau\cdot T_{ann}\cdot N_n\cdot[N^*_{av.}(1) – N^*_{av.}(v^*_{min})]$

where $T_{ann.}$ – annual quantity of conveyer work hours (let us assume $T_{ann.}$ = 8000 hours); τ – tariff 1 kW hour of electric energy (let us assume τ = 0.08 €/kW hour).

In relative units $E^*=E(v^*_{min})/E_1$, where E_1 – payment for electricity at nonregulated conveyer rate : $E_1 = \tau\cdot T_{ann.}\cdot N_n\cdot N^*_{av.}(1)$.

To build object function, let us use internal rate of return (*IRR*) of investment project.

IRR – is a discount, wherein the given cost-based and revenue sides of investment project are equal. Maximum value of IRR corresponds optimum efficiency of the project. Revenue side of the project is an annual profit E, representing annuity cash flow, given value of which is equal to [6]: $PV_E = E / r$, where r – discount.

Capital costs of the project – are the single costs, which do not require discounting. That is why the given cost input equals real cost: $PV_K = K$. From the equality of profitable and cost parts we have: $IRR = E / K$ or

$IRR(v^*_{min}) = \tau \cdot T_{ann} \cdot N_n \cdot [N^*_{av.}(1) - N^*_{av.}(v^*_{min})] / [A + B \cdot (1 - v_{min}^*)]$.

Maximum of this object function will correspond to the optimum value $v^*_{min\ opt.}$, which determines the required depth of conveyer rate control.

To generalize research results, there fulfilled simulation modeling of conveyer units work with parameters corresponding to IRR_{max}, but having different values of conveyer loading factor ($k_{loading} = Q_{av.} / Q_n$). Basing on the results of modeling, dependency diagrams of minimal velocity of control range $v^*_{min\ opt.}$, corresponding to them values of IRR_{max}., relative power consumption economy E^*, and also discounted pay-back period (*PBP*) on the conveyer loading factor $k_{loading}$ are presented in the figure 3.

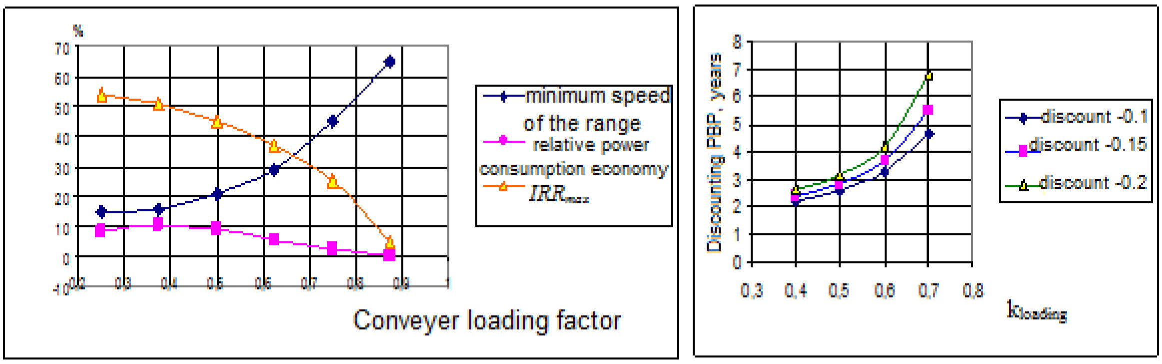


Figure 3. Dependency diagrams $v^*_{min\ opt.}$, IRR_{max}., E^* and *PBP* on the conveyer loading factor $k_{loading}$

Conclusions.

In result of diagrams analysis one may conclude that speed control is effective at the values of conveyer overall load $Q_{av} < (0.7\text{- }0.75)\ Q_n$. Energy saving at more higher values of Q_{av} is imperceivable (less than 1%). Relative energy saving is maximum at $k_{loading}$ 0.35-0.4 and makes about 10% towards the regime without speed control. Economically sound depth of rate control for conveyer electrodrive, determined by the optimal minimal value $v^*_{min\ opt}$, makes 0.15-0.4 at the following values of loading factor $k_{loading} = 0.3\text{-}0.7$.

Payback of investment projects of regulated electrodrives of conveyer units depends on the conveyer loading factor and on the discount of payback time estimation. Within the range of loading factors $k_{loading} = 0.3 - 0.7$ for discount r=0.1, discounted pay-back period is 2.2-4.7 years (minimum period of payback corresponds to minimum loading factor). Increase of estimation discount (r = 0,2) leads to increase of payback time respectively up to 2.6-6.9 years for the same range of loading factor change.

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